

E&P Focus

Fall 2013

Oil & Natural Gas Program Newsletter



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Water Issues Dominate Oil and Gas Production

What Is Produced Water?

Produced water is water trapped in underground formations that is brought to the surface along with oil or gas. Because the water has been in contact with the hydrocarbon-bearing formation for centuries, it contains some of the chemical characteristics of the formation and the hydrocarbon itself. It may include water from the reservoir, water injected into the formation, and any chemicals added during the production and treatment processes. Produced water is also called "brine" and "formation water." The major constituents of concern in produced water are:

- Salt content measured as (salinity, total dissolved solids, electrical conductivity)
- Oil and grease (this is a measure of organic chemical content)
- Various natural inorganic and organic compounds or chemical additives used in drilling and operating the well
- Naturally occurring radioactive material (NORM)

Produced water is not a single commodity. The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geological host formation, and the type of hydrocarbon product being produced. Produced water properties and volume can also vary throughout the lifetime of a reservoir.

Produced water is by far the largest volume byproduct or waste stream associated with oil and gas exploration and production. Approximately 21 billion bbl (barrels; 1 bbl = 42 U.S. gallons) of produced water are generated each year in the United States from nearly a million wells. This represents about 57 million bbl/day, 2.4 billion gallons/day, or 913,000 m³/day (Clark and Veil 2009). More than 50 billion bbl of produced water are generated each year at thousands of wells in other countries (Figure 1).

Early in the life of an oil well, the oil production is high and water production is low. Over time the oil production decreases and the water production increases. Another way of looking at this is to examine the ratio of water-to-oil volume:

- Worldwide average estimate – 2:1 to 3:1
- U.S. estimate – 5:1 to 8:1, because many U.S. fields are mature and past their peak production (Clark and Veil 2009), although the ratio may be even higher as water is not always measured directly.
- Many older U.S. wells have ratios > 50:1

At some point the cost of managing the produced water exceeds the profit from selling the oil. When this point is reached, the well is shut in.

Editor's Letter

Few topics elicit more response today than the issues surrounding produced and frac flowback water. The boom in shale development, with the consequent increase in fracturing water use and reuse, has upped the ante considerably. That, together with the aging of tradition wells leading to increased water cuts, has resulted in a sharp increase in water production, and increased pressure to dispose of and/or treat that water in a safe and environmentally responsible manner.

| Sample | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 | #11 |
|---|---------------|---------------|---------------|---------------|---------------|----------------|----------------|----------------|---------------|---------------|---------------|
| Specific Gravity | 1.026 | 1.036 | 1.019 | 1.012 | 1.07 | 1.1 | 1.17 | 1.105 | 1.066 | 1.02 | |
| pH | 7.92 | 7.51 | 7.91 | 6.61 | 6.72 | 6.68 | 6.05 | 7.11 | 7.04 | 6.83 | |
| Bicarbonate | 1,010 | 717 | 1,190 | 259 | 183 | 193 | 76 | 366 | 366 | 839 | 94 |
| Chloride | 19,400 | 29,400 | 10,000 | 6,290 | 59,700 | 87,700 | 153,000 | 96,400 | 58,300 | 11,500 | 19,730 |
| Sulfate | 34 | 0 | 88 | 67 | 0 | 0 | 0 | 670 | 479 | 0 | 3,100 |
| Calcium | 630 | 1,058 | 294 | 476 | 7,283 | 10,210 | 20,100 | 4,131 | 2,573 | 282 | 451 |
| Magnesium | 199 | 265 | 145 | 49.6 | 599 | 840 | 1690 | 544 | 344 | 40.7 | 1,330 |
| Barium | 49.4 | 94.8 | 6.42 | 6.24 | 278 | 213 | 657 | 1.06 | 5.1 | 97.4 | |
| Strontium | 107 | 179 | 44.7 | 74.3 | 2,087 | 2,353 | 5,049 | 178 | 112 | 45.3 | |
| Total Iron | 4.73 | 25.7 | 8.03 | 14 | 27.4 | 2.89 | 67.6 | 26.4 | 33.8 | 63.4 | 0 |
| Aluminum | 0.17 | 0.21 | 0.91 | 0.38 | 0.18 | 0 | 0.1 | 0.17 | 0.78 | 1.12 | |
| Silica | 33.8 | | 40.7 | | | | | | | 33.2 | |
| Boron | 28.2 | 27.1 | 26.7 | 8.82 | 45.1 | 73.1 | 80.4 | 94.5 | 65.7 | 4.79 | 4.5 |
| Potassium | 192 | 273 | 78.7 | 85.8 | 977 | 1,559 | 2,273 | 2,232 | 1,439 | 135 | |
| Sodium | 10,960 | 16,450 | 5,985 | 3,261 | 26,780 | 39,990 | 61,400 | 54,960 | 32,600 | 7,048 | 11,307 |
| TDS | 33,300 | 49,300 | 18,200 | 10,800 | 98,600 | 144,000 | 252,000 | 160,000 | 97,700 | 20,200 | 36,092 |
| TSS | 57 | 246 | 50 | 30 | 10 | 12 | 32 | 120 | 13,762 | 1,004 | |
| TOC | 89 | 64 | 133 | 180 | 218 | 70 | 143 | 266 | 235 | 344 | |
| <div> <div>fbw</div> <div>fbw</div> <div>pw</div> <div>pw</div> <div>pw</div> <div>fbw</div> <div></div> <div></div> </div> | | | | | | | | | | | |
| <div> <div>Woodford</div> <div>Marcellus</div> <div>Bakken</div> <div>Piceance</div> <div>GOM</div> <div>Sea water</div> </div> | | | | | | | | | | | |

Treating produced and frac water entails removing a number of chemical constituents. The degree to which these constituents must be removed depends on the subsequent disposition of the water. Removing specific amounts of various chemical constituents and total dissolved solids (TDS) may render the water suitable for reuse in fracturing operations but below regulations for discharge into waterways. The variability of produced and frac flowback quality (see table), in addition to the final intended disposition of that water, requires a multitude of different water treatment options.

Cost effective technologies for removing dissolved ions from water have been one of the most important research challenges for both public and private sector scientists for more than a decade. Because produced water can be disposed of through deep well injection at a cost that can be less than \$2 per barrel, the cost hurdle for these new technologies to become commercial can be very low.

To meet the variability of this demand, a number of treatment, reuse and disposal options have emerged from recent research, much of it funded by the U.S. Department of Energy's National Energy Technology Laboratory (NETL). Some of these are detailed in this issue of E&P Focus.

The Editor

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Daigle, T.P., 2012, Ultra Deep Water Discharge of Produced Water and/or Solids at the Seabed, 09121-3100-01 RPSEA (after TUV-NEL, 2010)

In contrast, coal bed methane wells initially produce a large volume of water, which declines over time. The methane production starts low, builds to a peak, and then decreases.

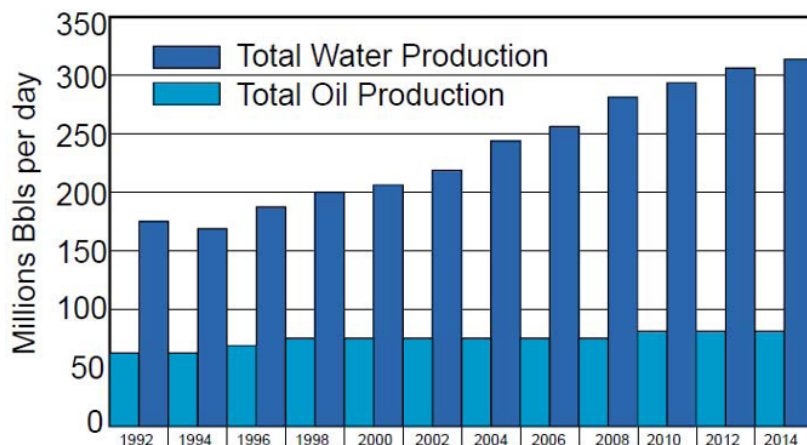


Figure 1. Global Oil and Water Production History and Forecast (TUV-NEL, 2010). The above figure highlights a major issue for the oil and gas industry. As the forecast oil production remains consistent, the produced water from this production continues to increase. The handling of produced water will become increasingly more important.

What is Frac FlowBack Water?

Flowback is a water-based solution that flows back to the surface during and after the completion of hydraulic fracturing. Frac flowback water is characteristic of the fluid used to fracture the formation, along with clays, chemical additives, dissolved metal ions and total dissolved solids (TDS). The water can have a murky appearance from high levels of suspended particles. Most of the flowback occurs in the first seven to ten days while the rest can occur over a three to four week time period. The volume of flowback water is anywhere between 20% and 40% of the volume that was initially injected into the well. The rest of the fluid remains absorbed in the formation.

Flowback water is not a uniform "raw material" from a process development perspective. The physical and chemical properties of flowback water vary considerably depending on the geographic location of the play, the geological formation, and the chemicals introduced during the drilling and fracturing operations. Moreover, flowback volume and water properties vary throughout the lifetime of the well. The flowback rate is highest initially and then decreases. Although there could be wide variation across geographical locations and due to operator bias, general flow profiles are shown below:

| Time Flowback rate | Flowback recovery | % frac fluid |
|--------------------|-------------------|--------------|
| 1-5 days | 100-150 bbl/hr | 10-25% |
| 5-15 days | 20-60 bbl/hr | 8-12% |
| 15-30 days | 5-10 bbl/hr | 1-5% |
| 30-90 days | 10 bbl/day | 1-2% |

The overall flowback after 90 days is in the range of 15 to 40%, but could be higher in certain wells.

As oil fields mature and water/oil ratios rise, and as increased levels of hydraulic fracturing in both oil and gas-bearing shales lead to increased volumes of flowback water, the challenges of cleaning and/or disposing of oilfield waste will only increase.

Zero-Discharge Water Management for Horizontal Shale Gas Well Development

West Virginia University, with partners ShipShaper, LLC, and FilterSure, Inc., have undertaken a project, with funding from NETL, to develop an on-site multi-media filtration system. The five-stage modular design will permit efficient system operation and treatment of flowback water at conditions that vary over time.

Background

Shale gas development in the Marcellus gas play in the northern Appalachian Basin requires large volumes of water to fracture the formation and stimulate production. Known as “frac return water”, it and produced water are highly saline and currently require either disposal or treatment for reuse or disposal. Both options are expensive. Produced water that cannot be readily treated for local disposal (e.g., land application) can be hauled to an injection well for disposal. These are EPA Class II wells permitted under the federal Safe Drinking Water Act and carefully controlled and monitored. Disposal costs are well established. In Texas, haulage and disposal costs average \$1.47 per barrel. In the more populated East, the costs range from \$1.68 to \$2.10 per barrel. As an alternative to deep well disposal, produced water has been processed at treatment plants (especially in Pennsylvania) but this practice is being scaled back.

The more cost-effective alternative is on-site treatment of the produced water to the degree needed for re-use as frac water. Produced water has been successfully treated using Reverse Osmosis (RO) as the primary treatment technology. However, extension of the RO technology to the treatment of flow back from hydraulic fracture operations has required pre-treatment technologies designed to extend the life of the RO unit. RO protection is especially important during the initial frac water return period when the water will contain the maximum suspended solids and minimum dissolved solids.

Re-use technologies are just now being implemented, and as reported in a recent Ground Water Protection Council overview: “Current levels of interest in recycling and re-use are high, but new approaches and more efficient technologies are needed to make treatment and re-use a wide-spread reality.” The FilterSure multi-media filter technology offers a new, cost-effective approach for removing suspended solids while promising an improvement in operating efficiency.

Impact

The successful development of an advanced multi-media filter technology for clean-up and re-use of frac return water will advance shale gas exploitation and development through improved economics and resolution of environmental issues. Improved economics will be achieved by the reduction of frac return water trucking and disposal costs. By reusing the frac return water for subsequent fractures, the need for new, fresh frac water for future wells will be reduced by 30% to 50%, depending on the percentage of injected water that is returned after the frac. There will be an additional cost savings due to reduced freshwater hauling, and labor costs will be minimized because the mobile unit will operate continuously with little or no need for an attendant.

Significant environmental benefits will be derived from this technology as well. Less fresh water will be needed for future fractures, thus lowering

the demand stress on local streams. Fewer trips with water trucks will cause less damage to local roads, reduce fugitive dust and engine exhaust emissions, and reduce mud and muddy water which potentially could pollute streams. These derived environmental benefits will also provide indirect economic benefits through reduced cost of road repairs, and less need for local stream remediation. Perhaps the most important benefit from cleaner and less disruptive water management will be the “good will” of all stakeholders affected by the shale gas development process.

Accomplishments

FilterSure installed the Mobile Treatment Unit (MTU) and conducted a field test at a Marcellus Shale well site (Figures 1,2). The MTU successfully supported a nine (9)-stage fracture treatment. The average filtration rate during fracture operations was 104 gallons per minute (GPM) with an inlet pressure of 52 pounds per square inch (PSIG). The MTU removed 32% of the solids, a result similar to that achieved in controlled laboratory tests at West Virginia University. During the test the MTU processed 280,000 gallons of produced water. Of the total volume of water sent to the MTU, 98.6% was recycled with only 1.4% sent for disposal.

The design phase of a 150 GPM unit has been completed. Testing of a 6 GPM MTU in the laboratory has shown that 150 GPM throughput can be reached.

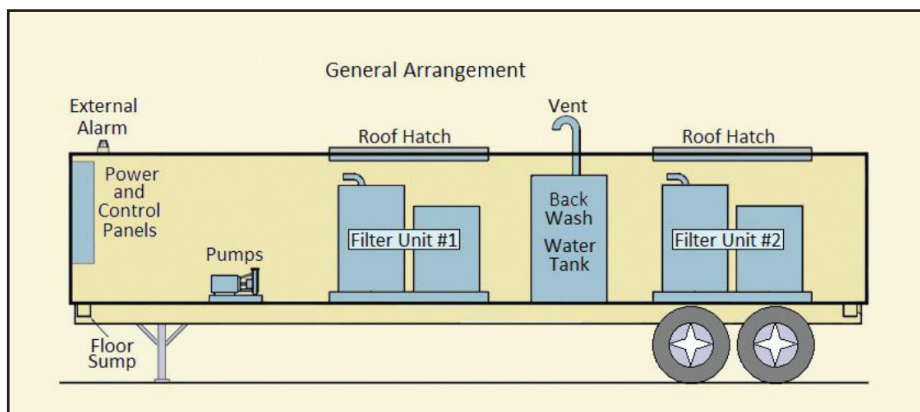


Figure 1. Equipment layout of the FilterSure Mobile Treatment Unit (MTU).

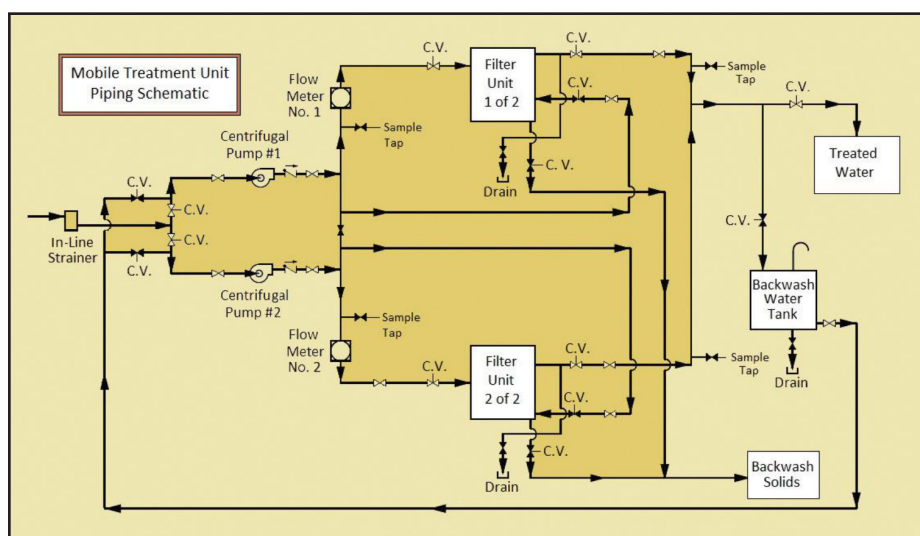


Figure 2. Piping schematic of the FilterSure MTU.

Results of Lab and Field Tests

During a laboratory test using actual frac return water from a site similar to the test site, WVU concluded that the new filter unit captured particulates at and greater than 3 microns in size. Current industry requests are equal to or greater than 20 microns, showing that even at high throughput the filter unit exceeds current industry needs.

No naturally occurring radioactive materials (NORMs) have been found in any of the field samples of frac return water received to-date. Any heavy metals and radioactive elements/compounds, if any, will be contained in the solids removed by filtration and managed as a part of the commercial process. Tests on the filter backwash waters following treatment of each sample showed “non-detect” levels for As, Cd, Cr, Pb, Se, Ag, and Hg. Barium was detected in amounts ranging from 1.61 to 5.33 mg/l, well below the Maximum Concentrated Level of 100 mg/l set for Ba.

One 20-gallon sample of Marcellus frac return water was shipped to a provider of Electrical Coagulation (EC) technology for testing as a potential pre-treatment option. The EC-treated water was returned to WVU for evaluation. The results show that the EC technology had a major impact on the distribution of the solids. Specifically, the EC technology caused the size distribution of solids to shift from a few microns in size to larger solids having a single bell-shaped distribution.

Three applications of FilterSure to Marcellus Shale frac return water reduced the suspended solids by 76%, removing all suspended solids greater than 3 microns in size, a good result when compared to the most strict industry requirement of 5 microns. Other industry operators stipulate either a 5 to 10 micron requirement or standard sand filtration with no absolute size requirement.

Suspended solids in the EC treated water were easily removed with the FilterSure technology, resulting in an effluent that was visually clear without particulates. The combination EC and FilterSure treatment system removed 99.4% of all particles.

Results of economic analyses indicate that the system resulting from this project will be very cost competitive in achieving the ultimate objective of zero-discharge of frac return water. Preliminary estimates place the cost at \$0.80 to \$1.22/barrel.

Responses to a questionnaire developed for this project are providing engineering information on volumes of flowback water and water chemistry requirements for recycling of flowback water. An Industry Contact Group was created to obtain representative water flowback samples and information on operating parameters.

The project ended in September 2012. A detailed final report can be found at www.netl.doe.gov/technologies/oil-gas. For additional information on this project, please contact William Fincham (william.fincham@netl.doe.gov or 304-285-4268) or Dr. Paul Ziemkiewicz (pziemkie@wvu.edu or 304-293-2867x5441).

Water Management Strategies for Improved Coalbed Methane Production in the Black Warrior Basin

The primary goal of this project is to analyze and develop strategies for water resource management within the coalbed methane (CBM) reservoirs of the Black Warrior Basin. Undertaken by the Geological Survey of Alabama*, the objective of the project was to develop a high-quality database and geographic information system (GIS). The objective of this system is to provide a basis for the development of efficient regulatory guidance by quantifying the environmental impacts of CBM produced waters and optimizing production operations and regulatory frameworks. Such regulatory guidance will help to provide environmental protection while simultaneously ensuring CBM delivery to the marketplace.

Background

Produced water management is a subject of increasing environmental scrutiny. Produced water can be a valuable commodity usable over a broad range of municipal, industrial, and agricultural applications. Some applications, such as using produced water for hydraulic fracturing, can increase efficiency while simultaneously reducing the costs of basic CBM operations. Use of produced water outside the CBM industry adds value to CBM production operations by facilitating industry, enhancing agriculture, and providing vital public services to communities affected by distressed water supplies. The CBM resource base in the Black Warrior Basin is estimated to be between 10 and 20 trillion cubic feet (Tcf). Cumulative CBM production stands at 2.1 Tcf and the most recent USGS assessment indicates that an additional 4.6 to 6.9 Tcf may be recoverable. Water management issues affect all CBM producers in the Black Warrior Basin. These issues need to be critically analyzed and addressed so that full CBM recovery potential can be realized.

Impact

The Black Warrior Basin has a long and rich history of CBM development. The wealth of data and the geologic diversity of the basin provide an unparalleled opportunity to evaluate water management strategies across a spectrum of reservoir conditions. Accordingly, this study will help natural gas producers develop basic geologic, hydrologic, and water management concepts that can be applied to CBM plays throughout the world. The study will apply a spectrum of geologic, hydrologic, geochemical, petrologic, GIS, and other computational techniques to characterize the Black Warrior Basin reservoir geology and basin hydrology. Study results should permit development of new water management strategies that will ensure environmental protection, foster beneficial use of produced waters, and improve reservoir performance.

Accomplishments

Eighty-six water samples were collected for geochemical analysis. Additionally, 25 gas samples were collected. Collection of these samples completed the sampling phase of the project. Analysis of these samples will enable further characterization of the relationship between water chemistry and the geologic framework, as well as aid in the development of water management strategies.

Reservoir performance has been analyzed through decline curves and production mapping (Figure 1). Numerous variations of production decline

*Note: In partnership with Black Warrior Methane, Coalbed Methane Association of Alabama, El Paso Exploration and Production, Energen Resources, Geomet, HighMount Exploration and Production and the U.S. Geological Survey

For additional information on this project, contact Chandra Nautiyal (chandra.nautiyal@netl.doe.gov or 281-494-2488) or Marcella McIntyre-Redden (mmcintyre@gsa.state.al.us or 205-247-3654).

For a listing of project publications please visit the project website at [http://www.gsa.state.al.us/gsa/cbm/Coalbed Methane Research.htm](http://www.gsa.state.al.us/gsa/cbm/Coalbed%20Methane%20Research.htm) [external site].

curves were identified and some have been found to be characteristic of specific producing areas. Areas where erratic production—due to frequent well maintenance or water management issues—is common have been identified and are indicative of inefficient gas recovery. These areas will be further investigated in order to develop water management strategies.

Discharge points where processed water is released into the Black Warrior River have been identified and incorporated into a geographic information system. Mapping of these locations aids in the development of water management strategies.

Researchers characterized the petrology of the Upper Pottsville sandstones, shales, and coals. Results of authigenic cement analyses indicate that sandstone composition has had no tangible impact on authigenesis. Stable isotopic analysis of the calcite cement that lines the natural fractures (cleats and joints) indicates cementation began locally early in the unroofing process in formation water with marine affinity; however, most of the cementation took place at or near modern burial depth and was associated with late-stage bacterial methanogenesis.

A manuscript was submitted for inclusion in a special volume of the International Journal of Coal Geology. Additionally, a manuscript, entitled “Dynamics of Thermogenic and Late-Stage Biogenic Gas Generation in Coalbed Methane Reservoirs of the Black Warrior Basin,” was delivered at the Unconventional Resources Technology Conference held in Denver in August 2013.

Going forward, researchers will continue mapping and analyzing geochemical data, as well as evaluating various water management strategies used in the basin.

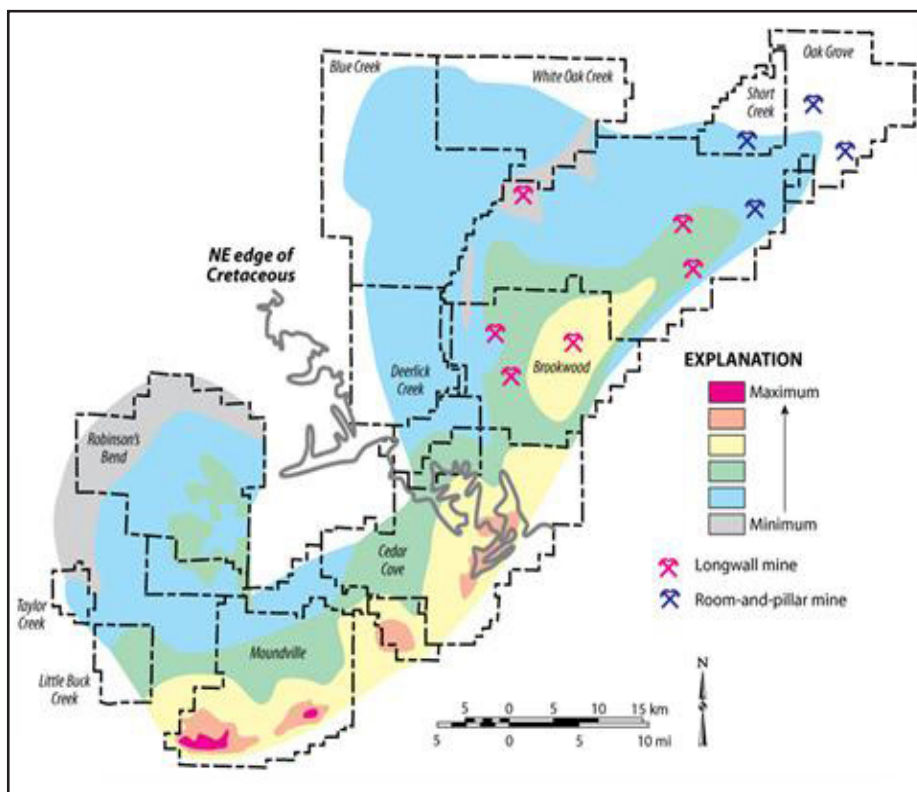


Figure 1. Distribution of original-gas-in-place for the Black Warrior Basin

Testing a Novel Low Temperature Desalination Concept for Wellhead Treatment of Produced Water

US Department of Energy research partners at the New Mexico Institute of Mining and Technology, together with Harvard Petroleum Corp., and Robert L. Bayless, Producer, LLC., have completed laboratory and field pilot testing of a system that relies on a low temperature distillation humidification dehumidification (HDH) process to remove salts from produced water. Longer term field testing of a 30 barrel per day (Bpd) prototype (now underway) will incorporate solar panels to provide heat for the process, increasing yields and reducing external power requirements.

Background

Produced water can be very saline, sometimes nearly six times as salty as seawater. For many smaller oil and natural gas producers faced with the need to dispose of large volumes of this brine in mature fields with tight operating cost constraints, the prospect of a low-temperature system that could desalinate the water at the wellhead is very attractive. Pure (or even less salty) water could be used for a number of oilfield operations (e.g., waterflooding, drilling fluids, stimulation fluids) and/or beneficial uses like irrigation, revegetation or livestock water.

Produced water desalination efforts have been focused on demineralization technologies that include reverse osmosis (RO), distillation, electrodialysis, freeze-thaw desalination, and ion exchange. Air stripping, activated carbon adsorption, membrane filtration, biological treatment and wet air oxidation have been widely investigated for removing the dissolved organic compounds that are also present in produced water. Unfortunately, applications of these technologies can be limited due to environmental factors (i.e., freeze-thaw works best in cold, dry climates) and energy intensity. Options are needed that are less energy intensive and applicable in a wider range of environments.

The HDH Process

The HDH process relies on the mechanism of air humidification at elevated temperature and water condensation at low temperature. Air can carry large amounts of water vapor at elevated temperature and that water vapor will condense when its temperature is dropped. In this system, air is used to scrub the produced water feed and then the feed water is sprinkled into the top of a chamber filled with packing material for enhanced water/air contact as air is pumped upwards from the bottom via a blower. The air is humidified as it travels to the top and then dehumidified in the adjacent condensing chamber. A large air-liquid contact area enhances water evaporation by forming a large area of thin water surface for contact with the forced air flow.

During the course of this research, bench-scale and field scale prototypes employing the HDH process were tested. The results revealed that the yield of desalinated water increases as the inlet feed temperature increases because the water carrying capacity of the air increases with inlet temperature. Supplemental energy sources for adding heat (solar panels and possibly co-produced geothermal energy) are being designed into the second phase field-scale prototype. Also, employing heat pump technology for enhancing latent heat recovery improves energy efficiency. Heat released by condensation can be transported to the evaporation side of the HDH unit as an additional latent heat source.

Economics of Desalination Technologies

Large-scale water purification techniques like multi-stage flash and reverse osmosis achieve operating costs on the order of \$0.70 to \$1.25 per barrel of treated water when large capacity units are employed. These technologies are expensive for small water processing volumes and are not feasible for locations with limited maintenance schedules and energy hookups. Initial evaluation of the results from this project indicates that costs on the order of \$0.45 to \$0.80 per barrel of treated produced water may be possible for a 20 Bpd capacity system. The main operating costs for the HDH system are related to energy costs for circulating pumps and heating of the inlet feed water.

The HDH process is most efficient at a relative humidity below 60–70%. While the “sweet spot” for deployment is in the desert southwest, including highly oil and gas productive regions such as the Permian, San Juan, and Paradox basins, the method would also be applicable in most Rocky Mountain producing areas and into portions of the Great Plains.

Phase I Results

Phase I of the project involved proof-of-concept for the HDH process using a bench-scale unit (Figs. 1 and 2), with the objective of understanding the influences of operational parameters such as feed water temperature, flow rate, carrying air flow rate on purified water quality, productivity, and overall water recovery rate. The results indicated that with a simple tubing-shell structured unit (where the separation column was built using a plastic shell column and copper pipes as the humidifier and heat exchanger), over 98% of dissolved salt was removed.

Experiments with produced water from a coalbed methane well indicated that both salt and dissolvable organics were removed efficiently by the HDH process. Total dissolved solids were reduced from 19,800 to 77mg/L while total organic carbon was reduced from 470.2 mg/L to 17.83 mg/L.

Phase II Results

The second phase of the project was to design and test a field prototype with a capacity to treat 30 Bpd of water. In these tests the total clean water yield from the process was 18 to 20 percent for the first pass of produced water. This result came after several iterations of design changes to optimize performance. The limit on inlet concentration was also tested and the process showed no drop in performance over a range of 8,500 mg/L to

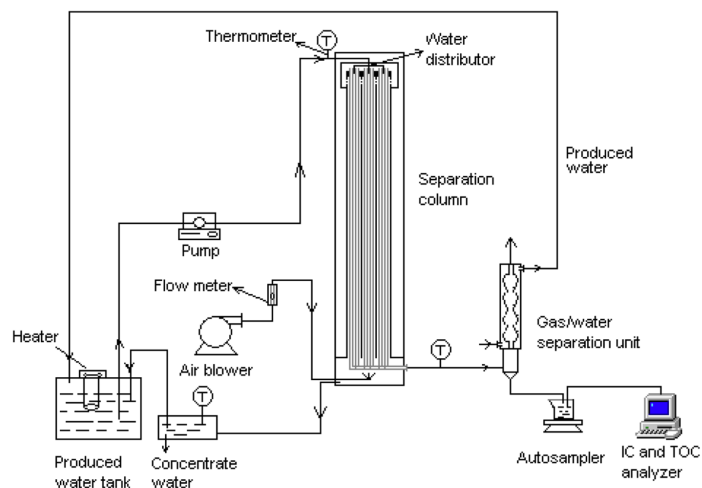


Figure 1. Schematic of laboratory scale HDH unit

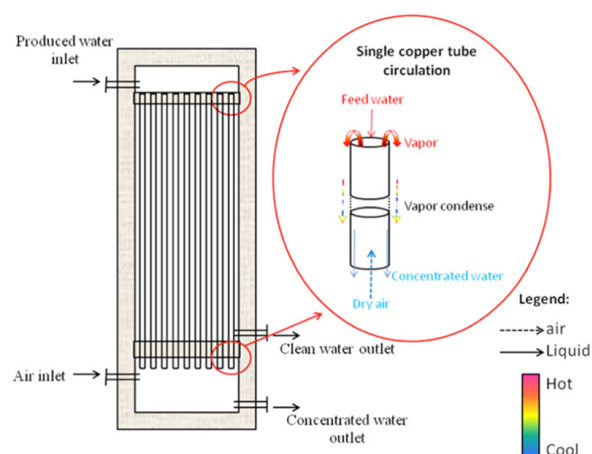


Figure 2. Schematic of separation system operation

250,000 mg/L of total dissolved solids (TDS). Ion rejection for the process was well over 99 percent with the purified water TDS values in the range of 200 mg/L or less.

The bench scale tests had identified some problems with the design, including insufficient heat transfer within the process chamber and leakage between chambers. Some of the design changes implemented in the field prototype versus the original bench design (see Figure 3) included:

- Simple oil skimmer to separate remaining oil from produced water
- Flat plate solar collectors sized to heat 20 Bwpd from 41 °F to 158 °F (during the prototype field testing a steam generator was used in place of the solar panels, which will be activated in Phase III).
- HDH unit with chambers made with stainless steel weirs designed for evenly spreading the water and cellulose-based packing material to increase the residence time of the fluid and maximize contact time between air and water (See Figures 4, 5)
- Cold trap to condense and collect purified water (Figure 6)

The field deployment of the system, installed in a shipping container, took place at a produced water gathering site in southeastern New Mexico. Throughput of 20 bbls per day during numerous 8-hour test periods was carried out over 43 days. The field test proved that produced water could be effectively desalinated using the HDH process, at atmospheric pressure and relatively low temperatures, with yields of up to 20 percent depending on the system configuration.

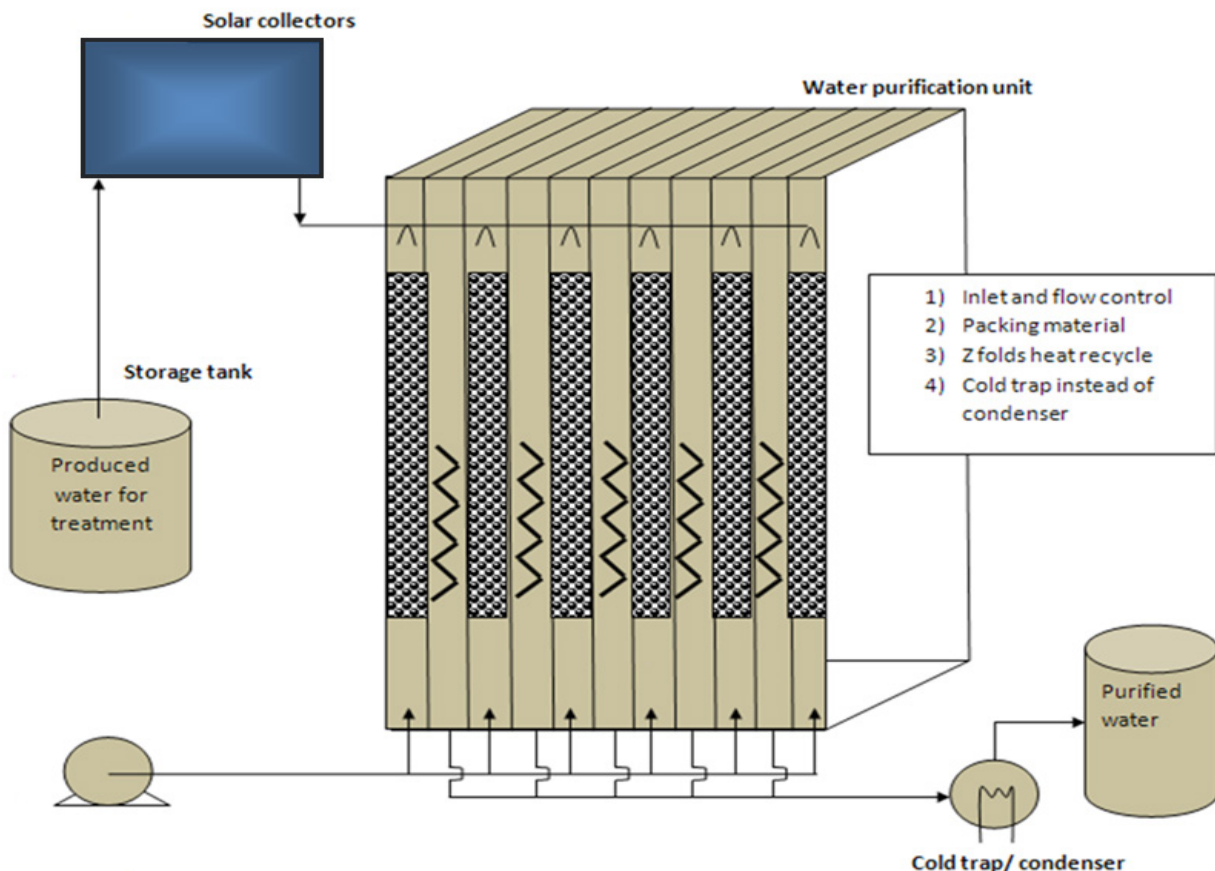


Figure 3. Schematic of field prototype design

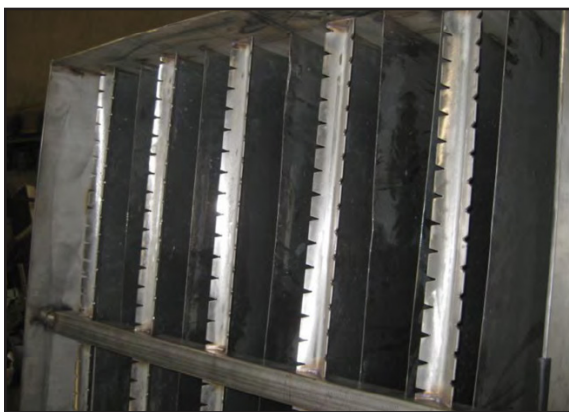


Figure 4. Top of HDH unit showing stainless steel weir construction

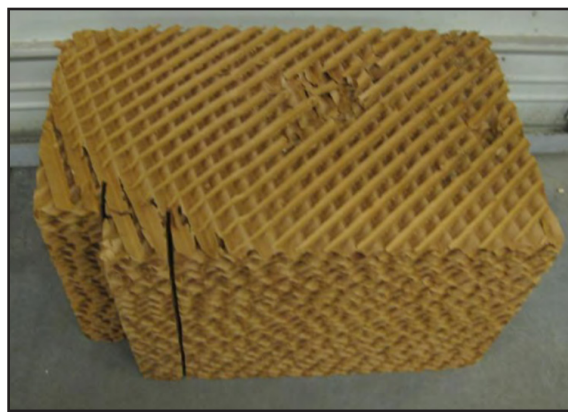


Figure 5. Packing material



Figure 6. Water purification system prototype inside shipping container as deployed at well site (HDH unit is stainless steel box in background, cold trap is blue box at left)

Next Steps: Continued Field Testing

The objective of the current phase of this project is to upscale the HDH process and demonstrate the viability and cost effectiveness of using solar energy to augment the process for continuous operation. The existing field prototype has been tested at up to 20 bbl/8 hours using somewhat arbitrary inlet rates. It should be feasible to triple that throughput and incremental increases to inlet rate may further increase the efficiency of this individual unit.

Solar panels have been sized to produce enough heat to maintain the cycle for 24-hour operations, even during winter months, with automation for continuous feed of produced water and utilizing solar panels and an insulated inlet water storage tank to “bank” heated water for overcast days and night operation. Additional testing to determine maximum throughput and most efficient throughput rates will be performed. Increased automation and maintenance parameters will be evaluated and put in place to allow unattended operation for days or weeks at a time.

Finally, a full-scale prototype will be constructed and operated at a field gathering site for a period of two months with the goal of reducing



Figure 7. Shipping container encased unit deployed at field produced water facility (steam generator and insulated water storage tank shown in front)

disposed water to less than 20% of original volume. Based on field testing with the prototype it is expected that with deployment of solar energy the electricity consumption for the HDH system can be reduced to 0.16 kWh per barrel and overall produced water purification cost to about \$0.18/barrel, considerably lower than that for commercial RO desalination processes and deep well injection.

Potential Impacts

Many marginal wells that produce less than 10 Bopd are operated near the edge of profitability by small operators, who generally do not own infrastructure for water transportation or facilities for disposal. Produced water must be hauled by truck to disposal sites, a costly process that can make an otherwise profitable operation uneconomic. This application of cost-effective technology for produced water purification could help to give new life to low-yield wells, result in a considerable decline in salt water disposal needs, and provide a clean water resource for land re-vegetation, oil production operations, or other beneficial uses. In addition, any reduction in deep well injection will reduce the risk of surface water contamination from transported produced water, and may also reduce the need for pipelines and associated rights of way, and reduce truck traffic and associated air pollution.

Additional Information

The final report for the first phase of this project has been published and is available at (<http://www.rpsea.org/projects/07123-05/>). For further information about this project, contact Chandra Nautiyal (Chandra.Nautiyal@netl.doe.gov or 281-494-2488) or Liangxiong Li (Li@prc.nmt.edu or 575-835-6721). In addition, two papers have been published or accepted for publication:

X. Li, S. Muraleedaraan, L. Li, and R. Lee, "A Humidification Dehumidification Process for Produced Water Purification," Desalination, in press, 2010.

S. Muraleedaraan, X. Li, L. Li, and R. Lee, "Is Reverse Osmosis Effective for Produced Water Purification: Viability and Economic Analysis," SPE 115952, Presented at the 2009 SPE Western Regional Meeting Held in San Jose, USA, 24-26, March 2009.



Technical Project Snapshots—Water Management

In addition to the projects highlighted in the previous section, a number of other, DOE research efforts focused on the treatment of produced water are summarized below. For details on any of these projects, search on the title or project number at www.netl.doe.gov or contact any of the Technology Managers listed on the front page.

Treatment and Beneficial Reuse of Produced Waters Using a Novel Pervaporation-Based Irrigation Technology (09123-11)

Objective: Develop a user-friendly model that may be used to assess the feasibility of the PV irrigation processes in areas defined by different climatic and site-specific conditions.

Performer: University of Wyoming

Progress: Laboratory tests have been completed. Based on permeate flux performance and observed rejection of salts, the pervaporation irrigation membrane process is a viable treatment technology for CBM produced waters.

Next Steps: Future work will concentrate on pilot site characterization, installation of the pervaporation irrigation (subsurface) lines and commencement of a long-term test to be followed by product evaluation and an economic assessment



NORM Mitigation and Clean Water Recovery from Marcellus Frac Water (10122-07)

Objective: Develop a cost-effective process to recover distilled water and a salable salt product from Marcellus frac flowback water.

Performer: GE Global Research

Progress: Lab and pre-pilot studies on several Marcellus frac waters have been carried out to establish a pretreatment process for NORM removal and membrane distillation (MD) equipment protection.

Next Steps: GEGR will conduct pilot validations of Marcellus frac water treatment and water recovery by MD.



GE Global Research

Basin-Scale Produced Water Management Tools and Options, Uinta Basin, Utah (11123-08)

Objective: Foster collaboration among producers, users, regulators, and local water management interests, providing information necessary for effective protection of alluvial aquifers, sustainable produced water management, as well as beneficial use of treated produced water.

Performer: Utah Geological Survey

Progress: Work has been initiated on compilation and analysis within a geographical information systems (GIS) format of past and new information on: thickness, structure, depth, and lithologic nature of all





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aquifer/reservoir units in the basin from the surface down through the Glen Canyon Group; the regional variations in quality of water, flow direction, and temperature produced from the various shale/tight sand gas reservoirs across the Uinta Basin; the location, saturated volume, and quality of alluvial aquifers; the existing infrastructure for water management/reuse; the energy generation potential of geothermal produced waters; and location and geochemical and hydrological characteristics of aquifers used/proposed for disposal of produced water or concentrated brines.

Next Steps: Compilation and statistical analysis of water production quantity and quality to identify and forecast produced water production volume trends for each discrete shale/tight sand gas producing interval.

Development of Plasma Technology for the Management of Frac/Produced Water (11122-31)

Objective: Demonstrate a novel plasma-induced water softening process.

Performer: Drexel University

Progress: The project was recently awarded and funded.

Next Steps: A coupled vapor-distillation process will be evaluated and reported

Advanced Treatment of Shale Gas Frac Water to Produce NPDES Quality Water

Objective: Develop a treatment process for flowback water that combines magnetic ballast clarification (MBC) for removal of total suspended solids, metals, and naturally occurring radioactive material, and vortex-generating and nano filtration membranes for removal of suspended and dissolved solids.

Performer: Southern Research Institute

Progress: The project was recently awarded and funded.

Cost-Effective Treatment of Flowback and Produced Waters via an Integrated Precipitative Supercritical Process

Objective: Evaluate the performance of an integrated precipitative supercritical (IPSC) process for treating fracturing flowback and produced water incorporating solids filtering, ultra-violet light treatment, chemical precipitation, and an advanced supercritical water reactor for removal of ionic salts.

Performer: Ohio University

Progress: The project was recently awarded and funded.



Advancing a Web-based Tool for Unconventional Natural Gas Development with Focus on Flowback and Produced Water Characterization, Treatment and Beneficial Use (11122-53)

Objective: Enhance an existing online produced water management tool by improving functionality and user choices, and enlarging the water quality database to include compositions of fracturing fluids, flow back, produced water, and baseline groundwater and surface water compositions for a variety of shale gas and tight gas plays.

Performer: Colorado School of Mines

Progress: The project was recently awarded and funded.

Development of GIS-Based Tool for Optimized Fluid Management in Shale Operations

Objective: Develop a GIS-based Optimized Fluids Management (OFM) tool that will access and analyze industry, regulatory, public, and research databases, and utilize a computational engine to provide equilibrium chemistry predictions and treatment process designs for a given set of water quality data.

Performer: Colorado State University

Progress: The project was recently awarded and funded.

Novel Engineered Osmosis Technology: A Comprehensive Approach to the Treatment and Reuse of Produced Water and Drilling Wastewater (10122-39)

Objective: Advance development of the forward osmosis, osmotic dilution, and novel ultra-filtration processes for treatment of drilling and stimulation wastewater and produced water. These processes utilize osmosis as a driving force to extract pure water from highly impaired water while minimizing the volume of the concentrated, contaminated stream.

Performer: Colorado School of Mines

Progress: Investigation of the impact of changes in casting (membrane manufacturing process) parameters and membrane polymers to improve flux and longevity for operations in fouling and scaling environments has begun. First generation of novel forward osmosis membranes (capillary membranes that enable forced flow on both sides of the membrane and are self-supported, versus conventional spiral wound membrane modules) manufactured by HTI were received by CSM and testing is underway.

Next Steps: Continue testing of novel membranes and complete characterization of membrane performance relative to more conventional membranes